Fast Running Tools for Explosions in Urban Environments

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Many of the "fast-running" blast effects tools available to date are computational algorithms with lookup table techniques to use the vast array of empirical data in the open literature on blast effects of structures and their individual components. For example, ConWep or TM5-1300, are DoD manuals that exist for obtaining peak overpressures at various standoffs and explosive amounts. These overpressures can then be cross-referenced against other empirical datasets to determine the damage to various structural components, such as columns or windows. The goal of this project is to investigate the utility of "fast-running" hydrocode and structural models and how these may be developed and used to augment or improve existing tools.

Project Goals

Our objective is to determine the feasibility of a rapid blast-structure analysis approach using blast pressures obtained from ALE3D or blast manuals (ConWep/TM5-1300), simplified engineering building models to determine the effects of those pressures on that building or structural component, and empirical data for structural damage. We then determine the probability of damage using advanced statistical learning techniques such as mixture modeling and/or sequential importance sampling.

Relevance to LLNL Mission

Blast effects engineers are attempting to develop their own fast-running tools for the purpose of selling them to government and private industry. The proposed LLNL-developed fast-running tool has the potential to be much better because of the state-of-the-art finite element tools (such as ALE3D and DYNA3D), advanced stochastic techniques that reduce the number of realizations necessary for a convergent lookup table, and the powerful computers at our disposal for lookup table population. Federal entities within DoD, DHS, TSA, and FEMA have need of such tools.

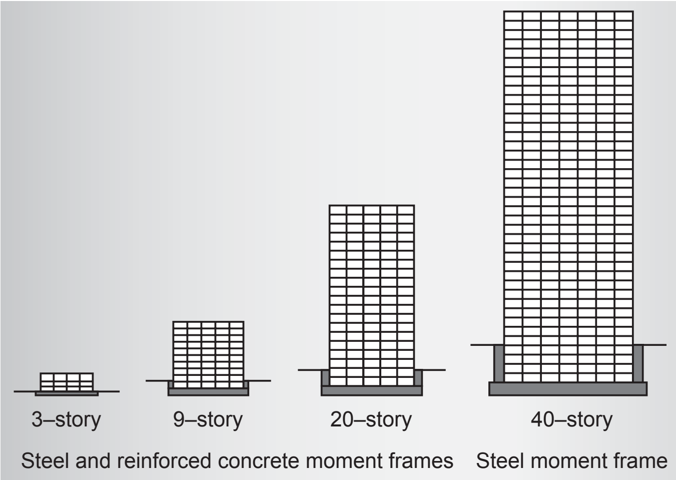

Figure 1. Schematic views of structures used in the study.

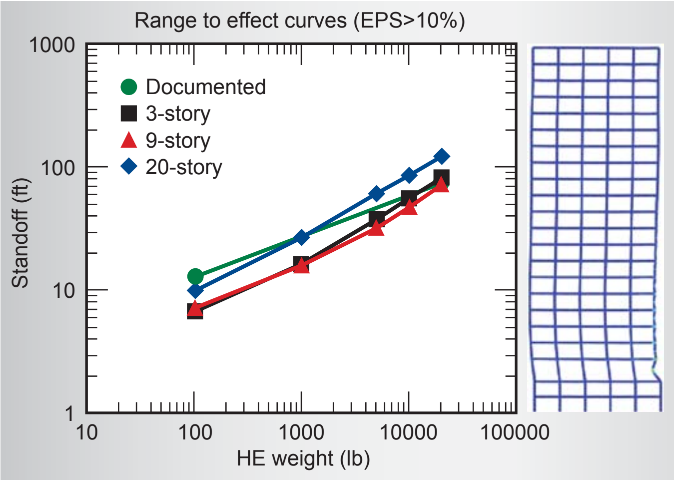

Figure 2. Range to effect curves for 3-, 9-, and 20-story steel moment frame building designs compared to documented empirical data. On the right is an example blast analysis of the 2-D 20-story structural model.

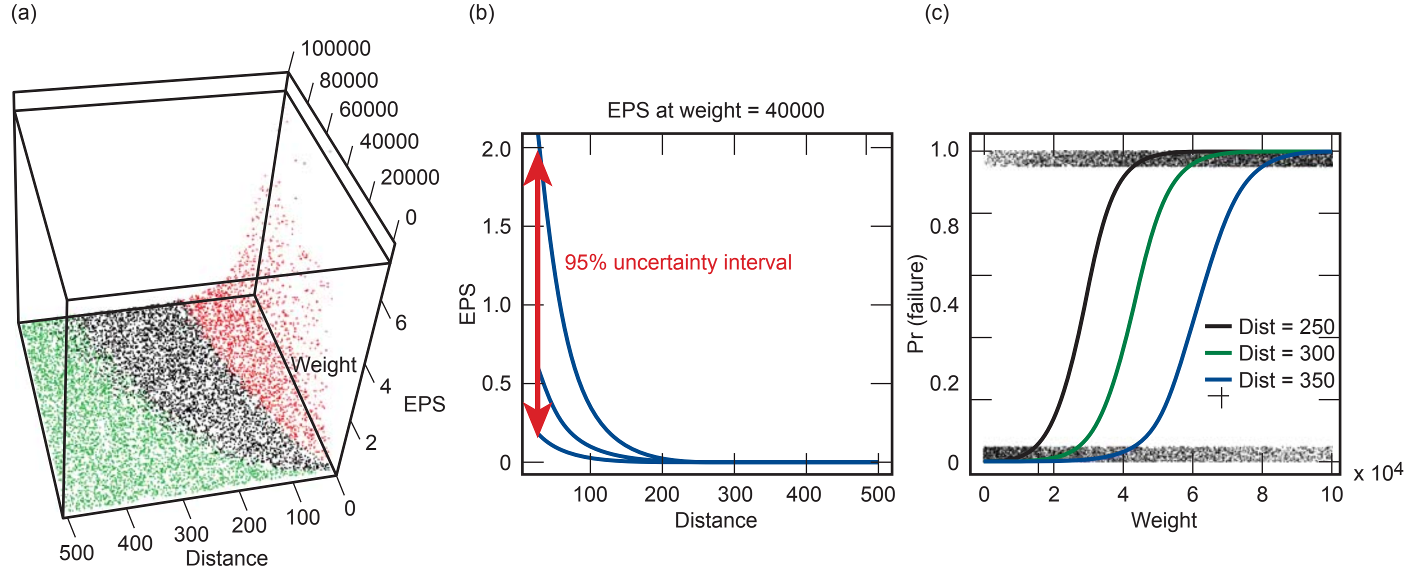

Figure 3. (a) Graph of 10,000 simulation results with green, black, and red points representing no damage, moderate damage, and severe damage, respectively; (b) EPS as a function of weight showing 95% uncertainty interval; (c) logistic curves showing probability of experiencing yielding or worse (EPS_{MAX}>0.1%) as functions of charge weight for specific values of distance.

FY2008 Accomplishments and Results

The canonical building models used for this effort were initially developed and designed at UC Berkeley for the Southern Nevada Ground Motion and Infrastructure Response Project at LLNL. The buildings had 3, 9, 20, and 40 stories representing low, medium, and high-rise office and residential buildings.

The linear elastic 2-D steel moment frame building models developed for the Southern Nevada Project were improved upon for this effort. The improvements included: developing the models for use in DYNA3D and NIKE3D; adding material nonlinearities; and adding the capability for the models to use Kingery and Bulmash equations to determine the blast loads on the structure.

In addition to modifying the 3-, 9-, 20-, and 40-story steel moment frame models (Fig. 1), a 3-D version of the 3-story building was developed for comparison with the 2-D model. The wall time to perform a blast analysis using these simplified beam element models is approximately 30 s for the 3-story structure to 3 min for the 20-story structure.

Multiple methods for applying the 3-D blast pressures to the 2-D models were studied. The results from the various methods were compared against empirical and historical data to determine the best method. Figure 2 shows the range to effect (charge weight versus standoff) comparison between the 3-, 9-, and 20-story building models and the empirical data.

After the building model validation, a stochastic analysis of the 3-story building model was performed. Our primary goal was to study the effects of charge weight and standoff on the resulting effective plastic strain (EPS) experienced by the structural elements. We generated 10,000 simulations varying the charge weight, standoff, yield stress, tangent modulus, and damping factor. Of primary interest were the variation and uncertainty of maximum EPS with the given sets of parameters. Maximum EPS was mapped (Fig. 3) into three categories of damage defined as follows: *no damage* (EPS_{max} < 0.1%); *minor to moderate damage* (0. 1% < EPS_{max} < 10%); and *severe damage* (EPS_{max} > 10%).

We used a logistic regression model to obtain probabilities of types of damage as functions of weight and standoff. Figure 3c shows a 1-D plot of the probability of "yield or worse" (EPS_{max} >0.1%) as a function of weight for three different values of standoff. Since a large fraction of EPS values are exactly zero we use a mixture model combining logistic regression for all data points and ordinary regression model for only positive EPS. The mixture model provides levels of confidence in the results, *e.g.*, in Figure 3b the 95% uncertainty interval on EPS_{max} decreases with distance for a particular charge weight.

As expected, other parameters (yield stress, tangent modulus, and damping factor) proved to have statistically insignificant effects on results compared to weight and standoff. It should be noted that Sequential Importance Sampling (SIS) can and should be used to reduce the number of realizations necessary to produce such response curves. For this, a user-defined "rare event" criterion will be needed, *e.g.*, search for onset of yield, EPS_{max} of 10% +/– d.

Related References

1. Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin, Bayesian Data Analysis, CRC Press, New York, New York, 2000.
2. James, J. W., T. M. Wood, E. M. Kruse, and J. D. Veatch, "Vehicle Bomb Blast Effects and Countermeasures," *35th Annual IEEE International Carnahan Conference on Security Technology*, October 16–19, 2001.